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HIERARCHIAL PARALLEL COMPUTER ARCHITECTURE DEFINED BY COMPUTATIONAL MULTIDISCIPLINARY MECHANICS*

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GOAL

Develop Architecture for Parallel Processor Enabling Optimal Handling of Multidisciplinary Computation of Fluid-Solid Simulations Employing Finite Element and Difference Schemes

Paper Outline

1. Goals
2. Paper Overview
3. Philosophical Directions
4. Modeling Directions
5. Static Poly tree
6. Dynamic Poly tree
7. Example Problems
8. Interpolative Reduction
9. Impact on Solvers
10. Summary
11. Future Directions

Philosophical Thrusts

1. Reduce Load Per Processor
2. Reduce Number of Processors
3. Reduce I/O Between Processors
4. Provide for Most Natural Route of I/O Flow Between Processors
5. Enable Optimal Handling of Model Topology
6. Enable Optimal Handling of Automatic Mesh Refinement
7. Provide Logical Framework to Implement Generalized Saint Venants Type Model Reduction

Modelling Directions

1. Static Single Level Models (Traditional Simulation)

- Modelling Requirements Defined Initially

- No Changes Occur During Computation

2. Dynamic Multilevel Models

- First Level of Model Refinement Established by User

- Multilevels of Refinement Established Via Automatic Physical Criteria ie.
  - Cavitation
  - Plasticity (Inelasticity)
  - Shock Formation
  - Flow Separation
  - High Stress and Strain Gradients
  - Etc.

STATIC POLY TREE PARALLELISM

Steps

1. Static Model Organized into Convenient Substructural Components

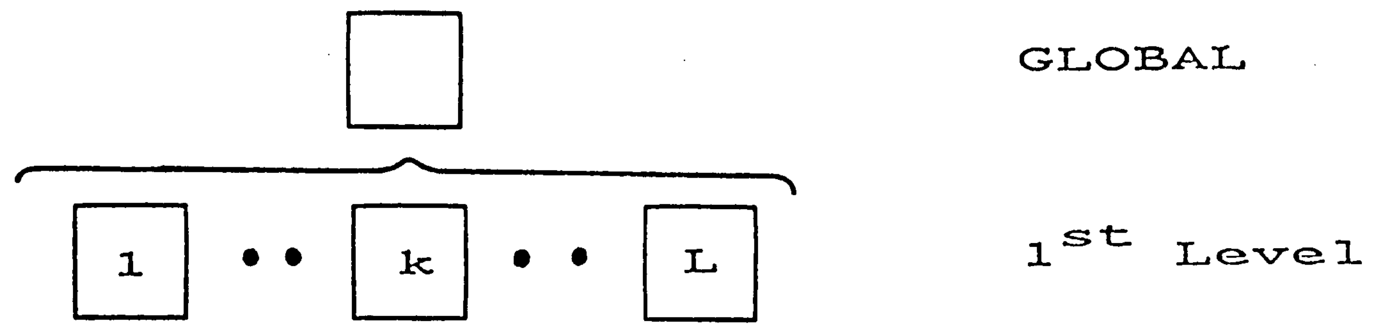
2. Each Substructural Component is Partitioned into Optimal Number of 2nd Level Substructures

3. The Various 2nd Level Substructure May Themselves be Partitioned into a 3rd Level

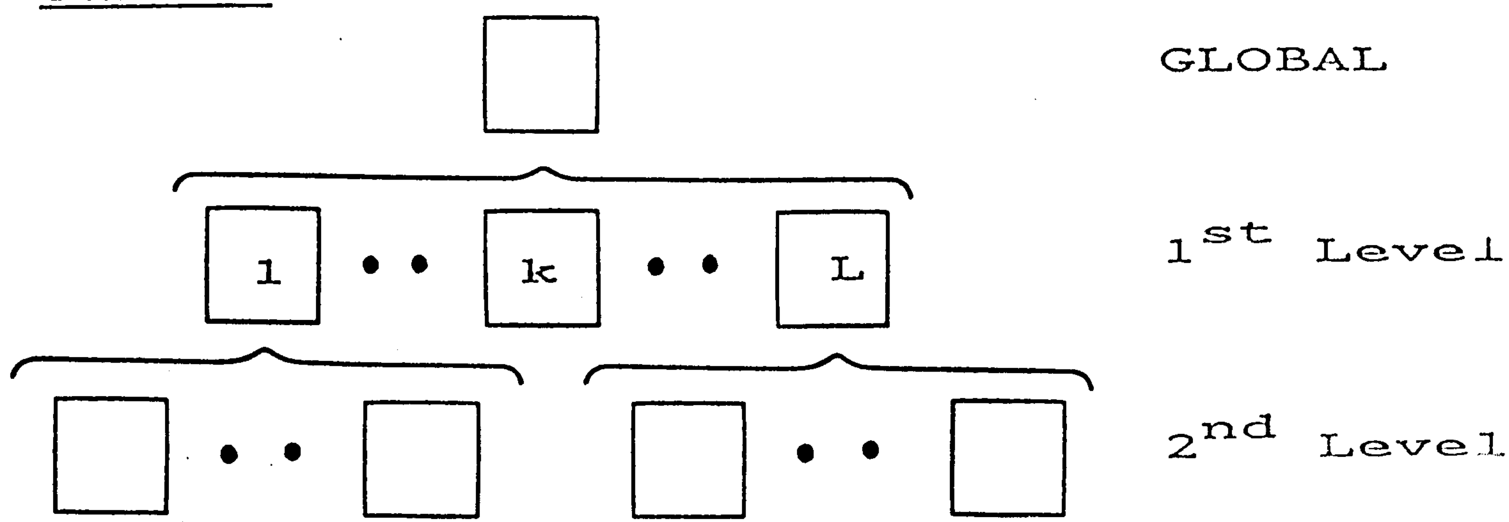
4. The Process May be Repeated to Yield a Multilevel Poly Tree

DEVELOPMENT OF STATIC POLY TREE

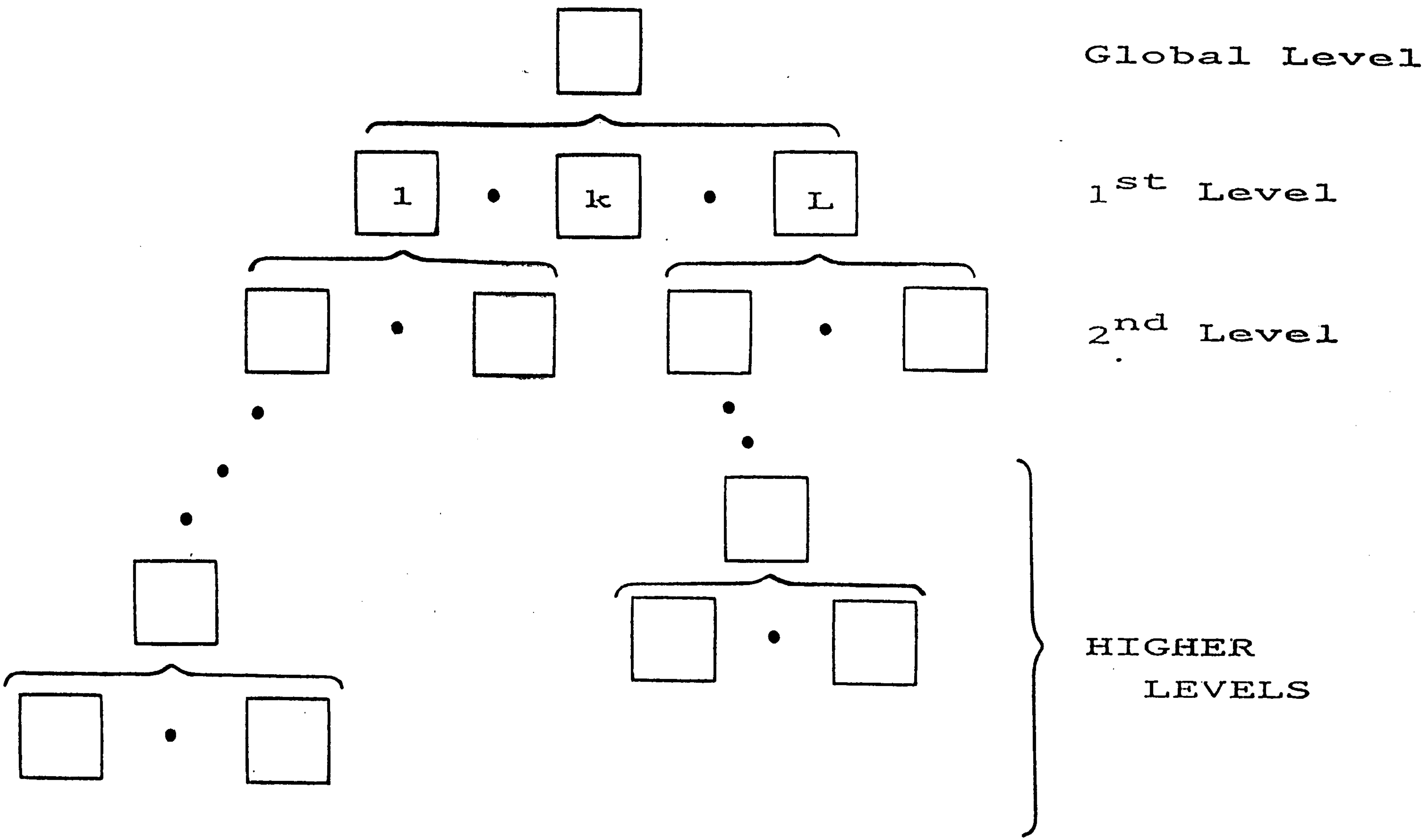
STEP 1



STEP 2



DEVELOPMENT OF STATIC POLY TREE



Choice of Levels and Associated Partitions : Static Model

1. Number of Boundary and Internal Variables at Each Level/Partition Balanced to Yield
   - Optimal Hierarchy of Bandwidths
   - Minimum I/O Between Levels

2. Choice of Levels Contingent on
   - Reducing Load Per Processor
   - Minimize Number of Processors for a Given Level of Speed Enhancement

DYNAMIC POLY TREE PARALLELISM

Steps

1. First Level Organized into Convenient Substructural Components (Optimal in Static Sense)

2. Each Substructural Component Refined as Per Local Physics

3. To Maintain Optimality, Refinements May Require Several Levels of Processors

Choice of Numbers of Level & Associated: Dynamic Model

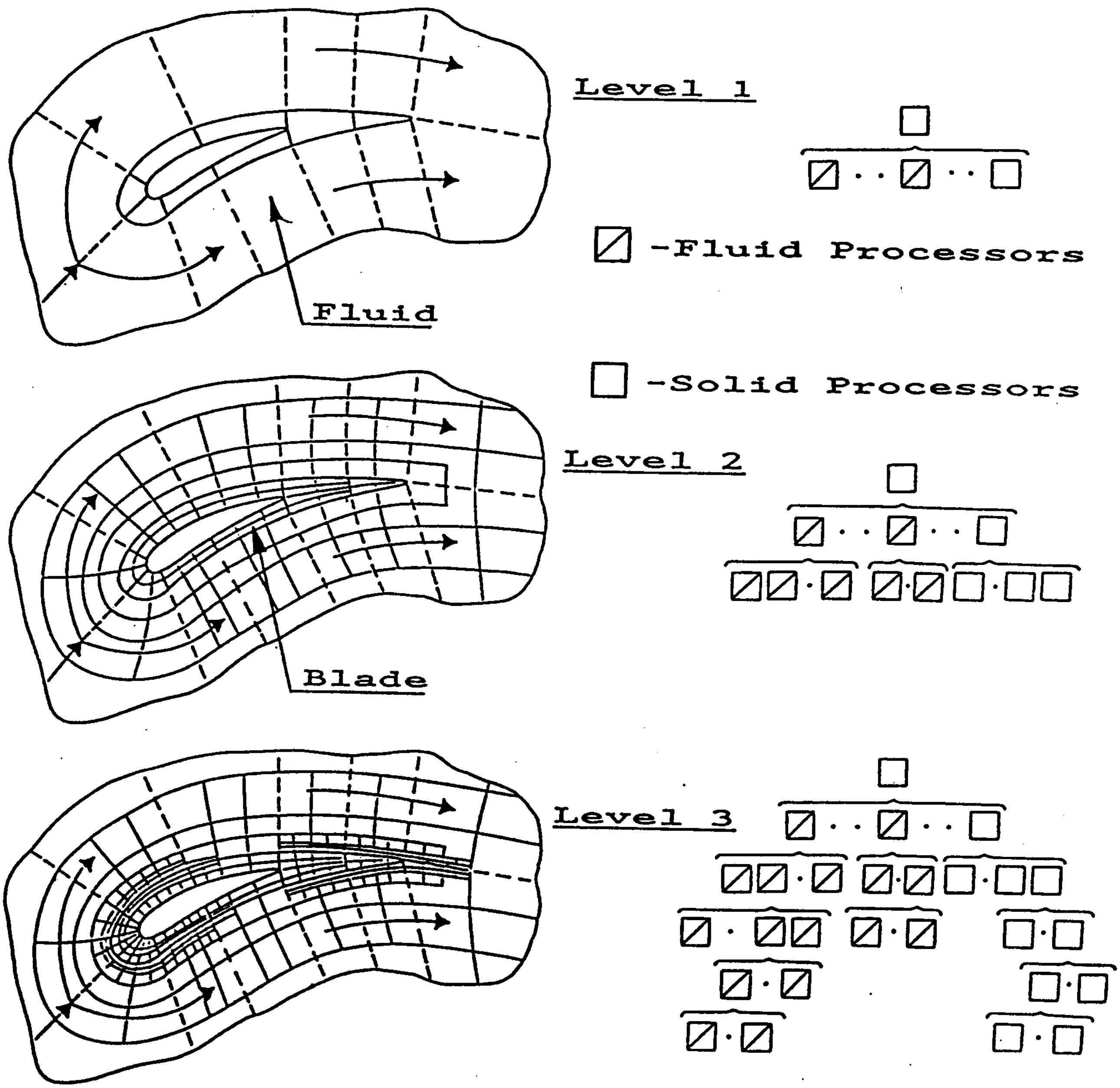
1. First Level Defined as Per Static Tree

2. Choice of Additional Levels and Associated Partitions Contingent on
   - Maintaining Optimality of a Given Branch of Poly Tree
   - Reducing Load Per Processor
   - Minimize Number of Processors
   - Maintain Balance Between Internal and External Variables
   - Minimize I/O Between Levels

OPTIMAL PARALLEL COMPUTER ARCHITECTURE FOR INTERDISCIPLINARY MECHANICS SIMULATIONS

Densifying Solid-Fluid Model

Dynamic Poly Tree Arrangement of Processors



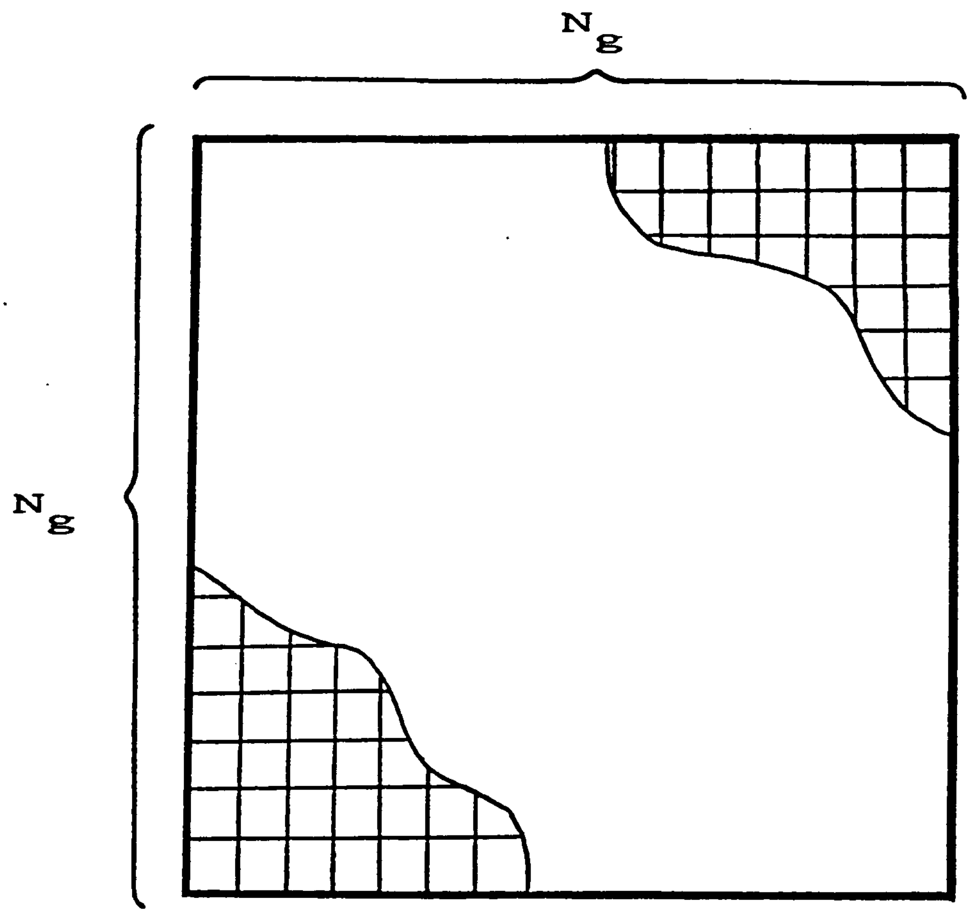
Example Problem

Given:

Consider Sqare Region With Fine Uniform Mesh

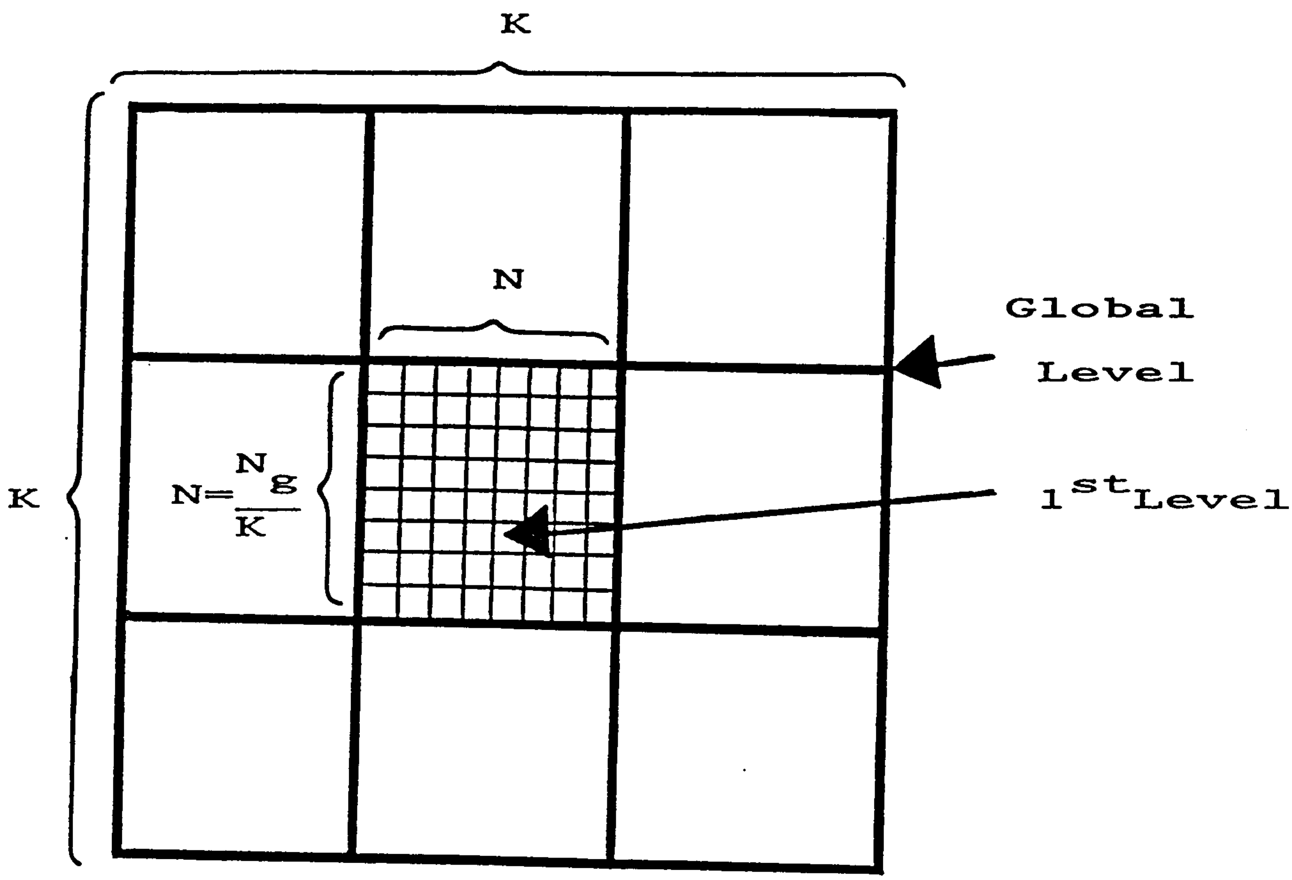
Problem:

Define Optimal Poly Tree

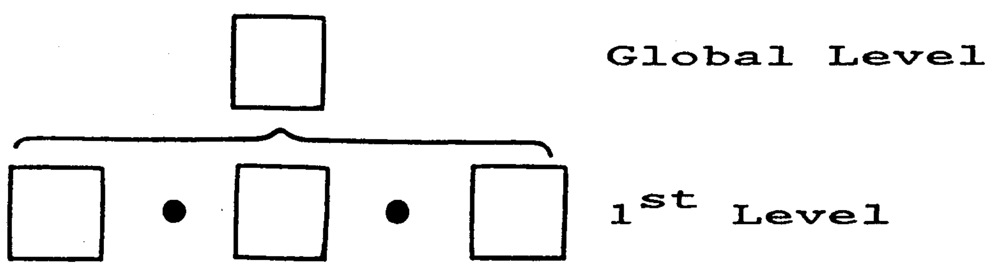


$(N_g)^2$ - Total Mesh Points

TWO LEVEL POLY TREE



POLY TREE



K^2+1 - Total Number of Processors

ASYMPTOTIC COMPUTATIONAL EFFORT:

TWO LEVEL

- STRAIGHT FULL SIMULATION

$$C_g \sim \frac{1}{4} (N_g)^4$$

- TWO LEVEL POLY TREE

$$C_0 \sim \frac{9}{4} K(N_g)^3$$

$$C_1 \sim \frac{9}{2} \left(\frac{N_g}{K}\right)^4$$

- COMMUNICATIONS

$$C_c \sim B_r(8(N_g)^2 + 8K\ N_g)$$

ASYMPTOTIC COMPUTATIONAL EFFORTS:

TWO LEVEL

- RATIO COMPARISON

$$R_{p/g} \sim \frac{\psi(C_0+C_1) + \frac{\Omega}{N_c} C_c}{C_g}$$

$$R_{p/g} \sim \psi\left\{\frac{9}{(K)^4} + 4.5 \frac{K}{N_g}\right\} + 8 \frac{\Omega B_r}{N_c}\left\{\frac{K}{(N_g)^3} + \frac{1}{(N_g)^2}\right\}$$

OPTIMAL SOLUTION

- GLOBALLY OPTIMIZED

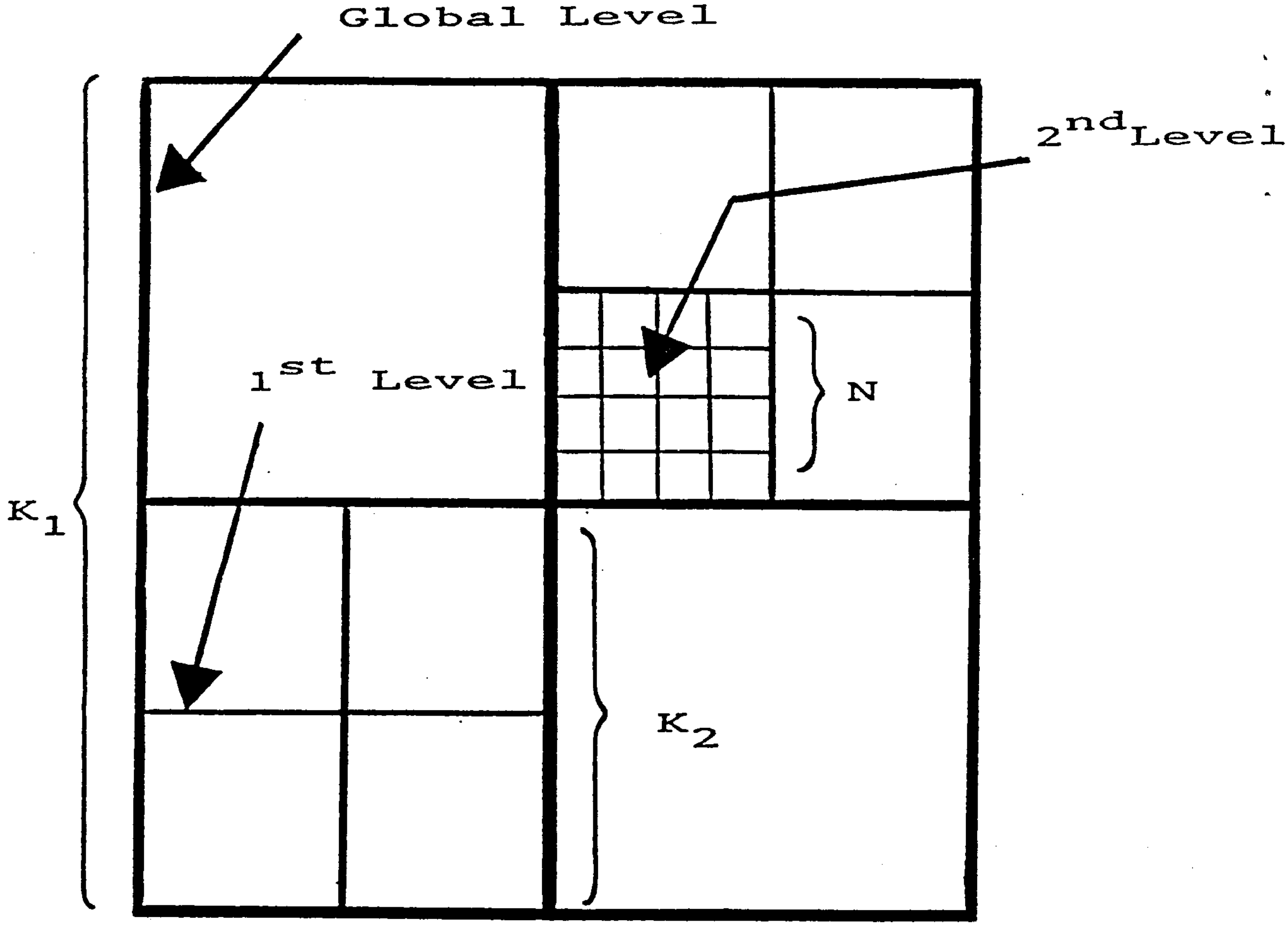
$$\frac{d}{dK}\left(R_{p/g}\right) = 0 \rightarrow$$

$$K \sim \left[8\, N_g \left\{ \frac{1}{1 + \frac{16}{9\psi} \frac{\Omega\, B_R}{N_c\, (N_g)^2}} \right\} \right]^{1/5}$$

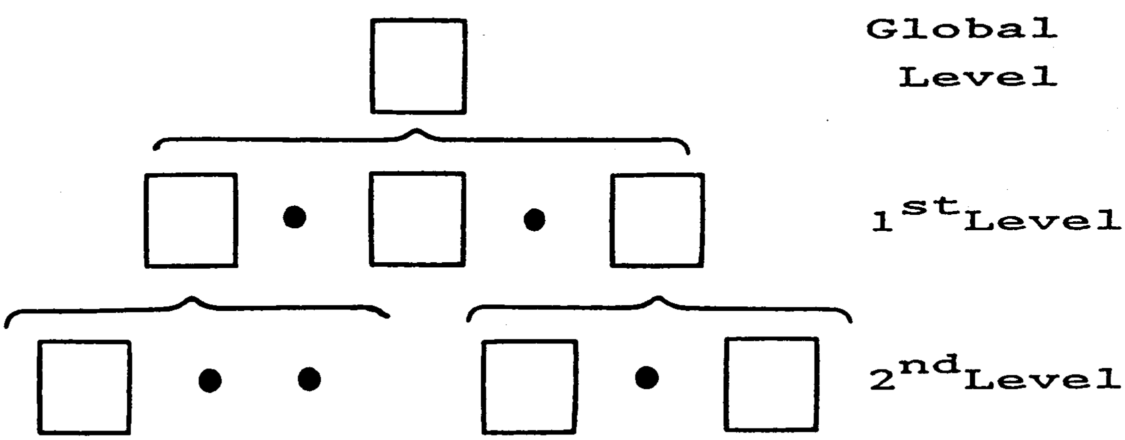
OPTIMAL TWO LEVEL POLY TREE

$(N_g)^2$	K	$R_{1/g}$	$R_{0/g}$	$R_{p/g}$	SPEED UP	NUMBER PROCESSORS
2.5×10^5	5	.045	.0144	.0594	17	24
2.5×10^7	8	.0072	.00219	.00939	106	64
2.5×10^9	13	.00117	.000315	.00148	673	169

THREE LEVEL POLY TREE



POLY TREE



ASYMPTOTIC COMPUTATIONAL EFFORT:

THREE LEVEL

$$C_0 = \frac{9}{4} K_1 (N_g)^3$$

$$C_1 \sim \frac{49}{4} \frac{K_2 (N_g)^3}{(K_1)^3}$$

$$C_2 \sim \frac{9}{4} \left(\frac{N_g}{K_1 K_2}\right)^4$$

$$R_{p/g} \sim$$

$$\underbrace{\frac{9}{(K_1 K_2)^4}}_{\substack{\text{2nd} \\ \text{Level}}} + \underbrace{\frac{49}{2} \frac{K_2}{(K_1)^3 N_g}}_{\substack{\text{1st} \\ \text{Level}}} + \underbrace{4.5 \frac{K_1}{N_g}}_{\substack{\text{0th} \\ \text{Level}}}$$

SUBOPTIMAL TRENDS: TWO LEVELS

$$R_{p/g} \sim \frac{9}{(K)^4} + 4.5 \frac{K}{N_g}$$

$K \rightarrow$ Large; $K \sim O(N_g)$

$$R_{p/g} \sim 4.5 \quad (450\%)$$

C-5

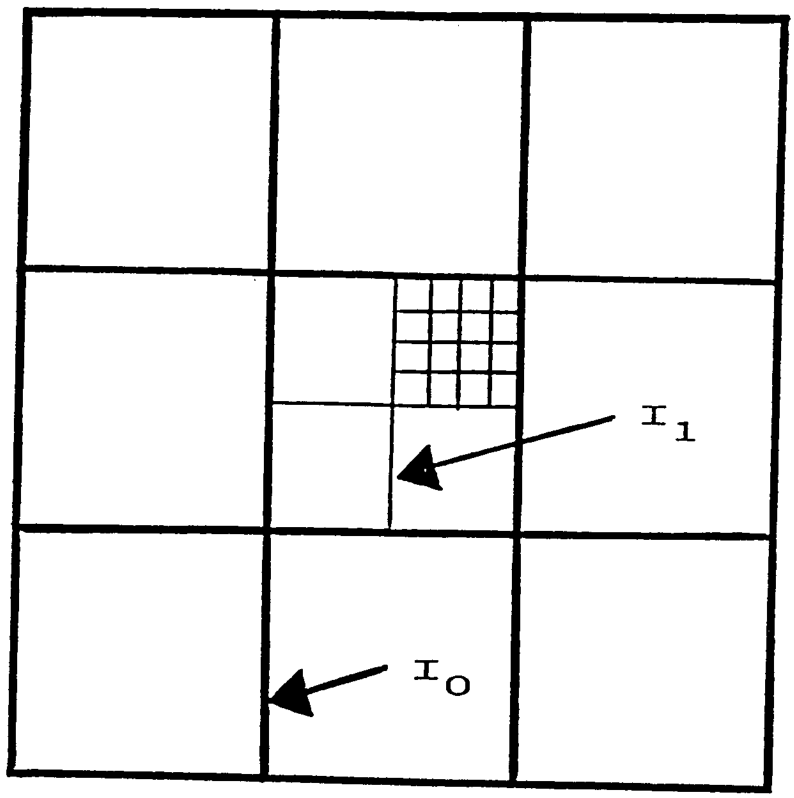
OPTIMAL THREE LEVEL POLY TREE; $N_g = 5000$

K_1/K_2	R_0/g	R_1/g	R_2/g	R_p/g	SPEED UP	NO. PROCESSORS
2/6	$.18 \times 10^{-2}$	$.37 \times 10^{-2}$	$.4 \times 10^{-3}$	$.58 \times 10^{-2}$	170	144
3/5	$.27 \times 10^{-2}$	$.91 \times 10^{-3}$	$.18 \times 10^{-3}$	$.38 \times 10^{-2}$	264	255
10/4	$.9 \times 10^{-2}$	$.19 \times 10^{-4}$	$.35 \times 10^{-5}$	$.9 \times 10^{-2}$	110	1600

OPTIMAL THREE LEVEL POLY TREE; $N_g = 50000$

K_1/K_2	$R_{0/g}$	$R_{1/g}$	$R_{2/g}$	$R_{p/g}$	SPEED UP	NO. PROCESSORS
2/8	$.18 \times 10^{-3}$	$.49 \times 10^{-3}$	$.13 \times 10^{-3}$	$.81 \times 10^{-3}$	1239	256
4/7	$.36 \times 10^{-3}$	$.54 \times 10^{-4}$	$.15 \times 10^{-4}$	$.43 \times 10^{-3}$	2335	784
10/6	$.9 \times 10^{-3}$	$.29 \times 10^{-6}$	$.7 \times 10^{-6}$	$.9 \times 10^{-3}$	1110	3600

INTERPOLATIVE REDUCTION : 3 LEVEL



MESH LEVEL	REDUCTION
Global	I_0
1^{st}	I_1
2^{nd}	1

INTERPOLATIVE REDUCTION: 3 LEVEL

$$C_0 \sim \frac{9}{4} K_1 \; (N_g)^3 \; (I_1 I_0)^3$$

$$C_1 \sim \frac{49}{4} \frac{K_2}{(K_1)^3 (N_g)} \; (I_1)^3$$

$$C_2 \sim \frac{9}{(K_1 K_2)^4}$$

$$R_{p/g} \sim$$

$$\underbrace{\frac{9}{(K_1 K_2)^4}}_{\substack{\text{2nd} \\ \text{Level}}} + \underbrace{\frac{49}{2} \frac{K_2}{(K_1)^3 N_g} (I_1)^3}_{\substack{\text{1st} \\ \text{Level}}} + \underbrace{4.5 \frac{K_1}{N_g} (I_1 I_0)^3}_{\substack{\text{0th} \\ \text{Level}}}$$

REDUCTION EFFECTS: THREE LEVEL POLY TREE;

$N_g = 5000$

$I_1 = \frac{1}{2}$, $I_0 = \frac{1}{4}$

K_1/K_2	$R_{0/g}$	$R_{1/g}$	$R_{2/g}$	SPEED UP STRAIGHT	SPEED UP REDUCED	NUMBER PROCESSORS
3/5	$5.3\text{x}10^{-6}$	$1.1\text{x}10^{-4}$	$.18\text{x}10^{-3}$	264	3386	225
10/4	$1.7\text{x}10^{-5}$	$2.3\text{x}10^{-6}$	$.35\text{x}10^{-5}$	110	42920	1600

REDUCTION EFFECTS: THREE LEVEL POLY TREE;

$N_g = 50000$

$I_1 = \frac{1}{2}, \quad I_0 = \frac{1}{4}$

K_1/K_2	R_0/g	R_1/g	R_2/g	SPEED UP		NUMBER PROCESSORS
				STRAIGHT	REDUCED	
4/7	7×10^{-7}	6.7×10^{-6}	$.15\times10^{-4}$	2335	44,640	784
10/6	1.7×10^{-6}	3.6×10^{-8}	$.7\times10^{-6}$	1110	402,250	3600

Impact on Solvers

Static/Dynamic Poly Tree Architecture Provides a Logical Framework for

- Direct Solvers
- Iterative Solvers
- Mixed (Direct/Iterative) Solvers
- Multi Time Scale Transient Solver
- Local/Global Constrained Nonlinear Solvers
- Mesh Refinement Procedures
- Interpolative Reduction (Saint Venants)
- Etc.

Summary

The Poly Tree Arrangement Yields

- Optimal Choice of Number of Processors Required for Given Problem
- Reduces Load Per Processor
- Reduces I/O Between Procesors
- Enables Optimal Handling of Automatic Mesh Refinement
- Provide Most Natural Route for I/O Flow
- Enables an Orderly Way to Perform Interpolative Mesh Refinement

Future Directions

1. Continue Refinement of Scheme
2. Develop Associated Parallel Solution Procedure
   - Direct
   - Iterative
   - Mixed
   - Steady State
   - Transient
3. Establish requirements of Data Based Management System Required for Overall Contol